Biotech Innovation in Europe's Food and Drink Processing Industry: Promise, Barriers and Exploitation

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Chapter for R. Rama (Ed.), *Innovation in the food and drink processing industry*, Haworth Press Inc, N.Y.

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1 Introduction

Early optimism about the potential of biotechnology to contribute to "the production of food with improved quality and nutritional content" (ACOST, 1990) has waned in the face of consumer resistance to the use of genetically modified organisms in food. The European food and drink sector has not abandoned biotechnology, however, but it is being very selective in its use. Some of the current applications of biotechnology were not recognized in early predictions about the application of biotechnology to the food and drink sector.

As general background, this chapter will first briefly review the characteristics of the European food and drink industry, including the factors explaining diversity in firms' responses to the opportunities for innovation in the sector. This mainly draws on detailed research carried out in the 1980s which identified the major trends affecting innovation in the industry (Senker, 1987). Much less research was carried out subsequently, and this smaller body of research gives no indication that these conditions have changed significantly (Mangematin and Mandran, 2001). The next section will discuss the many opportunities for product and process innovation in the food and drink industry provided by advances in biotechnology. It focuses specifically on biotechnology applications to the food and drink sector and excludes those connected with agriculture. The third section will review information about the factors that have promoted and held back the exploitation of biotechnology by Europe's food and drink firms. The fourth section will present evidence about the industrial exploitation of biotechnology by European agro-food firms. This includes results from the European Commission funded European Biotechnology Innovation System (EBIS) project[1] as well as recent information from two countries (Finland, Ireland) on firms' strategies to apply biotechnology to the food and drink sector. On the basis of the material presented, the conclusion will consider progress in biotechnology innovation in the European food and drink industry in the next five to ten years.

2 Background

2.1 Structure and other Characteristics of the Sector:

Food products and beverages is the second largest manufacturing sector in the EU, and the largest manufacturing sector in Denmark, Greece, Spain, The Netherlands, Portugal and the United Kingdom (European Commission, 2003). The European food and drink sector is very large in terms of the number of firms as well as the number of employees, as shown in Table 1. This table also shows that France, Germany, Italy and the UK are the major food and drink manufacturing countries in the EU, accounting for approximately two-thirds of production. Poland has the largest food and drink sector of the new member states, with production totalling over €25 billion in 2002. The Czech Republic, Slovakia, Hungary and Slovenia together did not quite match Poland's production (Sausen, 2004).

[1] The EBIS project was funded by the European Community under the Targeted Socio-Economic Research Programme, contract number SOE1-CT98-1117 (DG12 - SOLS).

Table 1: Food and drink sector, companies and employment, 2001

	Production € billion	# of firms	# of employees (000s)
Austria	11[b]	1,264[b]	79[b]
Belgium	24[b]	723	62
Denmark	17[b]	450	87[b]
Finland	8[b]	336	34
France	115[c]	3,604	392[c]
Germany	110	6,035	597
Greece	5	1,036[b]	43
Ireland	15	687	47
Italy	93	6,800[d]	268
Luxembourg	1	226	4[b]
The Netherlands	39[b]	855	147[b]
Portugal	10[b]	1,916[d]	104[b]
Spain	67	3,040	371[b]
Sweden	13[c]	244	53
UK	98[b]	2,319	506[b]
Europe 15	626	29,635	2,796

Note: [b] more than one employee; [c] more than three employees; [d] more than nine employees.

Source: Confederation of the food and drink industries of the EU (CIAA) Website, *Statistics and trends, Countries* available at: http://www.ciaa.be/uk/library/statistics/countries.htm

Many different product markets comprise the food and drink sector:

- Cereal products
- Beverages
- Confectionery and snacks
- Fish and fish products
- Processed fruits and vegetables
- Oils and fats
- Dairy products
- Meat products

Despite the large number of firms, the sector is dominated by a small number of very large multinational corporations (MNCs) like Danone, Diageo, Nestle, Unilever and Heineken, which coexist with a large number of small firms. Thus "concentration at the EU level is fairly high: on average, the 5 firm concentration ratio is 30%…" (Regional Policy Directorate General, 2002) with MNCs dominating many individual product markets. Concentration has been explained as a response by food manufacturers to a range of pressures including globalisation, a response to growing concentration of food retailers[2] and increasing regulation of food connected with food safety, health and traceability (EMCC, 2004). Many MNCs have diversified and are represented across a range of product markets. Small firms tend to specialize in specific product markets and can thrive by responding to demand for specialist products in niche markets (e.g. ethnic, organic and vegetarian foods).

[2] In 2003, the leading 10 European food retailers accounted for 40% of total retail sales (EMCC, 2004)

Small and medium sized firms continue to co-exist with large multi-national firms in the food and drink sector. Different reasons explain this co-existence. Indeed, food processing is technologically straightforward and efficiency can be achieved even at a small scale. In addition, producers and transformers have to keep close to the source of production and/or to their markets. However large firms predominate in sectors such as sugar or vegetable oil refining and in instant coffee processing where plant size provides significant economies of scale. Mechanisation, batch automation and continuous flow processing have been applied to food processing (Wilkinson, 1998), but small and medium sized firms take advantage of the fact that current consumer demand for food is influenced more by considerations of quality and authentic craft-based production practices than by low-cost or standardisation (Byé, 1998).

However, the large food and drink MNCs gain economies of scale from sharing a common distribution network or from advertising (Horst, 1974). They can also access foreign markets through direct investment abroad. Foreign markets present problems for small companies, both for those selling perishable or bulky foods and those who find it too costly or difficult to adapt their products to satisfy the tastes or eating habits of foreign consumers.

The percentage of firms in the food and drink sector that innovate is high, although they have a low research capacity (Christensen et al, 1998). In France, for instance, a survey (1986-90) found that 70% of food and drink firms that responded to the Community Innovation Survey (CIS), reported innovations but less than 5% of them had internal research capacities (Mangematin and Mandran, 2001). The key to competitiveness in the food and drink industry is time to market and product costs. Thus, a high level of innovation (according to the CIS definition[3]) co-exists with a low level of patents, with food technology patents only accounting for about 1% of European patent applications (European Patent Office, 2004). This finding is not surprising in light of sectoral R&D expenditure, which is often used as an indicator of companies' capability to innovate. Traill and Grunert (1997) show that the food industry has one of the lowest ratios of R&D expenditure to value added of any industrial sector. Furthermore, Galizzi and Venturini (1996) point out that the food industry "is characterized by a low R&D intensity, radical innovations are absolutely rare and R&D is only a minor component of expenditures for implementing non-price strategies".

There are several reasons for this low R&D intensity. It is partly related to the innovation regime in the food and drink sector: incremental improvements result mainly from know how and on-going process improvements rather than from formal R&D. Thus, patenting to protect innovations is lower than in other sectors. Food and drink manufacturers mainly benefit from innovations protected by trade secrets: unique process plant or complex product formulations (e.g. Coca-Cola). Low R&D intensity also results from companies' poor ability to benefit from such investment. Unlike the low-volume, high value-added products of the pharmaceuticals sector, the food and drink sector is mainly concerned with high-volume, low value-added products,[4] that have poor prospects for recouping investments in R&D. New product development is an expensive and risky business for food manufacturers, undertaken in the belief that development and promotion costs plus some element of profit will be earned before imitations appear on the market. However, "response time" (the time it takes for

[3] The CIS definition of innovation is a new product or process for the firm, a new product or process for the market, a combination of a new product and process or an new organisation.

[4]The food ingredients subsector (flavourings and colourings) is an exception. It has similar characteristics to the pharmaceuticals sector.

imitations to appear) is facilitated by the activities of powerful food retailers in sourcing "own-label" products and the wide availability of standard process plant and statutory food labelling (Senker, 1987). Thirdly, the propensity of SMEs to patent is lower than that of large firms and the sector contains a very high proportion of small firms which target small or local markets.

To sum up, the food and drink industry is a mature industry with low margins because of the purchasing power of concentrated food retailers. Innovation in the food and drink industry is not predominantly science based, and that is why patents are not an appropriate method to measure innovativeness in the food and drink sector. It is mainly based on incremental improvements and incremental change to product formulation or design. Such innovations, based on know how, are not patented as they can be easily imitated (Oxley, 1997).

2.2 Sources of Innovation:

Anne Lebars (2001) has identified four sources of innovation for the food and drink sector. These are:

i. Relations with suppliers. Suppliers' research and/or incremental improvements to their products are an important source of innovation in the food and drink sector. For instance suppliers make a significant contribution to production plant design to reduce costs or improve product quality.

ii. Quality and regulation. The food and drink sector is highly regulated. Quality or sanitary norms may lead to innovation to conform with new standards.[5] According to firms' managers, this is a strong incentive to innovate, especially for SMEs; it enables them to remain in business.

[5] Millstone (1994) has shown that regulation of the food sector both hinders and promotes innovation.

iii. Improvements in the knowledge base. Increased knowledge can stimulate innovation in food and drink sector, especially for firms undertaking R&D who have close links with public sector research.

iv. The demands of food distributors. Food retailing is highly concentrated in Europe, especially in Finland, France, Germany, Sweden and the UK. The specific requirements of food retailers provide a strong incentive to innovate. Senker (1986) showed that food manufacturing innovation and the direction of innovation in the UK was driven by R&D performing multiple food retailers. By giving technical advice and the assurance of orders, they had stimulated innovation and lowered the entry barriers for suppliers of own-label food products).

2.3 Factors Affecting Firms' Innovative Behaviour:

Many factors affect the way that food and drink manufacturers respond to opportunities for innovation. Part of their response can be explained by the orientation of the companies, as presented in the following classification (Burns, 1983):

i. agriculturally-oriented firms either process raw food materials to be suitable for further manufacture, for example flour milling and sugar refining, or preserve the commodity, for instance by bottling, canning and freezing fruit and vegetables. They seek to produce standard products at minimum cost and often rely on by-products for profitability. Such companies are likely to be interested in process innovations that minimize energy costs or reduce the waste of raw materials. Innovation may also focus on processing the raw material into its basic components (sugars, starches, fats and proteins) so as to produce standardized, intermediate products (thickeners, sweeteners, concentrates, flavourings, colourings etc.) with well-defined technological and nutritional characteristics (OECD Observer, 1980) for manufacturers of more highly processed foods. Agriculturally-oriented companies may also develop product innovations based on waste products.

ii. consumer-oriented firms manufacture more highly processed convenience foods, such as breakfast cereals, biscuits, chocolate and sugar confectionery, from inputs that are typically produced by agriculturally-oriented firms. Such companies are likely to be interested in innovations connected with new preservation or packaging techniques that extend shelf-life, or with new process technologies that allow them to introduce new consumer products.

Recent studies show that the R&D expenditure of European food manufacturing companies is correlated with the development of new products (Traill and Meulenberg, 2002) and that product innovations are more important than process innovations in the innovation strategies of the largest firms (Arundel et al, 1995). European consumers are conservative about the food they choose to eat (Galizzi and Venturini, 1996) and most innovations in the food industry tend to be incremental[6] rather than radical (Huiban and Bouhsina, 1998; Menrad, 2004). In other words, consumer unwillingness to accept highly innovative products makes food and drink companies unwilling to exploit the opportunities offered by radical technologies such as biotechnology.

[6] Incremental innovations are innovations which are new for the firm but which already exist in the market. Radical innovation are innovations that are new for both the firm and the market (OECD, Programme Oslo Innovation Workshop 9-10 February 2004)

3 Potential of Biotechnology for the Food and Drink Sector

Biotechnology has been defined as "the application of biological organisms, systems and processes to the manufacturing or service industries" (ACARD/ABRC/The Royal Society, 1980). This definition has been further refined in terms of its application to the food sector as "the use of living cells, or parts of them, to produce or modify foods and food ingredients" (Jeffcoat, 1999). Traditional applications of biotechnology in the food and drink sector include plant and animal breeding, cheese- and yoghurt-making and the use of yeast to leaven bread and ferment alcohol. Second-generation food biotechnology is based on attempts to screen and categorize enzymes and micro-organisms in the natural environment and exploit those with useful applications. It includes the identification of enzymes for use as food ingredients and the long-standing use of microbial fermentration to manufacture citric acid, glutamic acid and nucleotides for use as flavour enhancers. Similarly, micro-organisms are used for the production of mycoprotein.[7] Modern biotechnology dates from the early 1970s and is based on scientific breakthroughs in genetics and molecular biology (recombinant DNA and monoclonal antibodies). It enables the manipulation of genes and alterations to the genetic structure of cells.

Jeffcoat (1999) differentiates the application of traditional biotechnology from those of modern biotechnology; the former focuses on making products using fermentation technology, while the latter is directed at tailoring ingredients for a specific end-use. Modern biotechnology applied to food is based on a combination of molecular genetics, applied enzymology and fermentation technology. Jeffcoat (1999), Hüsing et al (1999) and Menrad et

[7] Mycoprotein (brand name Quorn) was developed by Rank Hovis McDougall when searching for a cheap, vegetarian protein food with which to feed the Third World.

al (1999) identify six areas where there are opportunities for applying biotechnology to the food sector:

i. Control of raw materials through their manipulation and selection in plants or animals;
ii. Modification of raw materials to improve their performance;
iii. Production of novel ingredients;
iv. Modified process plant to reduce environmental burden and improve efficiency and quality; and
v. Production of new diagnostic and analytical tools.

3.1 Control of raw materials[8]: The major components of raw materials for food production are proteins, fats and carbohydrates and the minor components, often termed additives, include colours, stabilizers, flavours, enzymes, preservatives, vitamins and thickeners. Better control of raw materials has many advantages including influencing the flavour of the food to be produced, standardising plants to produce a high level of the component required (e.g. oil in seeds) so as to reduce the need for purification and downstream processing, and lessening the need for chemical processing to produce intermediate components with the desired characteristics. Better control of raw materials is also achieved through plant tissue culture to produce flavours and spices (e.g. mint oil, saffron, ginger).

3.2 Modifying raw materials and producing novel ingredients:[9] There is the potential for micro-organisms or isolated enzymes to modify the raw materials from plants and animals to produce novel ingredients. For instance a process using enzymes has been developed to

[8] Mainly based on Jeffcoat (1999)

[9] Mainly based on Jeffcoat (1999)

produce a natural emulsifier from egg yolks that has enhanced heat stability. Such applications are still held back by lack of scientific knowledge and skills, low cost enzymes and appropriate processing systems. Novel ingredients can also be produced by fermentation. There has been a long trend to replace natural ingredients with a broad range of flavours produced by fermentation. Recombinant DNA can also be used to increase the production of scarce enzymes from microbial sources. For instance, there is a shortage of the enzyme that clots cheese, commonly known as rennin. It is usually obtained from calves' stomachs, but Gist-Brocades has genetically modified yeast to produce this enzyme.[10]

3.3 Process plant applications: The large amounts of waste products generated by the food and drink manufacturing process cause an environmental burden. The application of biotechnology to the processing system could alleviate this problem and biotechnology could also be used to convert waste products into marketable products. One engineering company has cooperated with an enzyme firm and a food company to develop plant using biocatalytic processes for the processing of seed oil. This has led to a substantial reduction in waste, as well as savings in the use of toxic processing aids. Other seed oil companies in several countries have also implemented this process. To date, the introduction of process-integrated biocatalysis has been initiated by firms’ interest in improving process plant efficiency, not in meeting environmental standards for reducing pollution; existing technology enables them to comply with these standards (Hüsing et al, 1999).

3.4 Diagnostic and analytical tools[11]: There is great demand for analytical and diagnostic tools in the food and drink sector to deal with a wide variety of different applications. In the

[10] It is sold as Maxiren® see http://www.dsm.com/dfs/dairy/products/enzymes/~en/index.pl?f=maxiren.htm

[11] Based on Menrad et al (1999).

past these tools were based on physical and chemical methods. New methods for analysis and diagnosis based on biotechnology have supplemented, and even replaced conventional methods. The new biotechnology methods include:

i. Enzymatic assays, including bioluminescence to detect dirt and stains on food-processing equipment and other surfaces, so as to improve cleaning efficiency and the hygiene of processing equipment.
ii. Biosensors for food processing mainly focus on the determination of carbohydrates, mostly glucose. However, many promising biosensors developed by academics have failed to live up to their promise when put in contact with food samples. This is thought to be due to the high complexity of the samples.
iii. Immunoassays based on monoclonal antibodies that are able to detect pesticides or dangerous food pathogens.
iv. Nucleic acid based assays are able to detect specific DNA sequence material. They have numerous applications including monitoring infectious agents in crop production, animal husbandry and food processing; controlling the identity of production strain and starter cultures and identifying the origin of raw materials and components of processed food.

A recent Delphi survey investigated which applications of modern biotechnology to food production and food processing might come to fruition in the future. The applications with the brightest prospects are connected with diagnostics, and with the use of genetic engineering to produce enzymes. With regard to the former, they suggest that:

> "technologies such as DNA chips, presently at the threshold of revolutionizing analytics and diagnostics in human health care, can also be transferred to the Agro-Food sector. This may result in the broad application of inexpensive, easy-to-use and automated assays in the Agro-Food sector" (Menrad et al, 1999).

In relation to food enzymes they note strategic decisions by leading producers of enzymes to use genetic engineering as a core technology. They conclude that most food enzymes will be produced by organisms in the "near to mid-term future", that the time to market for new enzymes will be drastically shortened, and there will be a much larger variety of enzymes commercially available than previously (Menrad et al, 1999).

This brief review of the potential applications of biotechnology to the food and drink sector shows that there are innovation opportunities for both mature and new product sectors. Many of the opportunities seem more relevant for application by agriculturally-orientated firms than those in consumer-orientated sectors (see section 1.3). However, most of these opportunities are related to various suppliers in the food chain, rather than directly to food and drink manufacturers. For instance, changes to food raw materials may rely on the activities of the seeds industry; the development of new food ingredients, such as enzymes, may depend primarily on fine chemical companies; similarly, innovation to process plant is connected to initiatives by its manufacturers or to those of consultant engineers providing specialized equipment. Diagnostic tools may come from research equipment suppliers. Food packaging firms may also find ways to integrate biotechnology in their products, for instance to indicate food spoilage. However, some large MNCs may have subsidiary companies involved in some of these activities, or could cooperate with their suppliers in the development of such innovations. Indeed, an analysis of the patents of food and drink multinationals shows that they have significant in-house capabilities in biotechnology (Alfranca et al, 2004).

The ideal model for biotechnology innovation has been based on practice in the R&D intensive pharmaceutical sector. One of its most striking characteristics is the wide pervasiveness of networking between dedicated biotechnology firms (DBFs), multinational companies and academic researchers, or distributed innovation (Coombes and Metcalfe, 2000). The example of lactic acid bacteria patents (where Europe has a dominant position) shows that DBFs play a negligible role in biotechnology innovation in food science. Most R&D connected with these patents is collaboratively organized, with a single multinational company[12] collaborating with one or several public research organisations.[13] The firms involved have competence in relevant biotechnology and the research knowledge that allows them to collaborate with external research partners. Moreover this distributed innovation system is based on incumbents (the multinational food companies) recognising and assessing the ways in which biotechnology can augment their existing technologies. The mandate of government food research institutes, involved in food safety, food quality and the formulation of standards and regulation, has provided them with the specialized knowledge that enables them to contribute to defining relevant research to be undertaken. According to Valentin and Jenssen (2003), university scientists are ill equipped to identify relevant research questions in agro-food production as this mainly concerns problems of “know-how”, but they are able to contribute problem-solving skills. However, exploiting biotechnology opportunities confronts

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[12] This includes both specialized food ingredients suppliers (Chr. Hansen of Denmark) and very large, differentiated multinational companies like Unilever and Nestlé.

[13] As pointed out by Kalaitzandonakes (2000) public investment in agrobiotechnology is high and compensates for the lack of private investment.

many barriers, even for sophisticated MNCs. These difficulties are discussed in the next section.

4 Barriers to Biotechnology Innovation

Lack of confidence in receiving economic benefits from an innovation is the major barrier to the introduction of new technologies by firms'. Conversely, the promise of quick profits from investment in a new technology acts as an incentive for innovation. Companies do not anticipate that biotechnology innovation will prove beneficial to them for many reasons. It involves costly R&D and there are long delays between developing products and bringing them to market, caused by the need to meet regulatory requirements. Moreover, food and drink processing firms may not realize the full benefit of biotechnology innovations when they are produced by dedicated firms with strong appropriation regimes based on patents. Thus, dedicated biotechnology firms are more likely to benefit from innovative activity, not the food firms which take risks in applying their innovations. Secondly, the bargaining power of large scale retailers strongly influences product prices. Food and drink firms do not anticipate being able to negotiate increased prices for innovative products that lack obvious value for the consumer.

Another barrier to the introduction of new technologies by firms is their tendency to base innovation on technologies that are familiar to them. Indeed, it is extremely difficult for them to extend their existing knowledge base into new areas of innovative activity. The firms that do undertake in-house R&D often focus on the quality, variability or hygiene of the raw materials for the specialized sector in which they operate (e.g. dairy products, or meat products). They do not have any in-house competence to exploit advances in biotechnology, and there are no incentives for them to develop such competence. Menrad et al (1999) note that this lack of expertise in European small and medium sized food firms limits their demand for biotechnology processes and methods based on new enzymes or diagnostic tools, and this could have negative effects on the willingness of their suppliers to innovate.

Moreover, firms are also reluctant to introduce radical process innovations when the existing manufacturing facilities are functioning well, because of the high cost, long pay-back period and difficulties for its integration with existing plant, processes and routines (Hüsing et al, 1999). Companies' uncertainty about the economic value of investing in biotechnology has been exacerbated by public opposition to genetically modified organisms (GMOs) in food. The public is worried about the health and safety implications of the new technology, as well as the ethical issues raised. Regulatory delays and uncertainty, and public rejection of GMO food are discussed below.

A complex system of regulation ensures the safety and quality of the products manufactured by the food and drink industry. It is complex because there are numerous ways in which food can be harmful to consumers. These include the adulteration of food or drink by "fungal mycotoxins, hazardous bacteria, poisonous chemical additives or toxic pesticides, or which has not been handled or processed safely" (Millstone, 1994). A wide range of different types of regulatory instruments are used, and differ from country to country. Regulation in some countries, for instance, may cover matters like minimum standards of staff training, or registration of premises on which foods are processed, stored or sold. The regulation of novel food products[14] is even more complicated, and these procedures cover genetically modified

[14] The author was told by a former Research Director of the company that developed Quorn, that it would never have begun the project if it had been aware of the amount of work and time demanded to provide the documentation to meet regulatory standards for novel food products.

foods. Regulation covers manufacturing processes and demands rigorous assessment of toxicological, nutritional, compositional and other relevant data. Where the new food is proved to be substantially equivalent to one already on the market, it is not regarded as a novel product.

There are several reasons why the regulation of novel foods deters innovation: the cost of compliance is very high, there are long delays in copleting the regulatory process and there is great uncertainty about if or when returns can be realized on investments in innovation. The Novel Food Regulations were introduced by the EU in 1997. They cover food that contains GMOs, consists of GMOs or is produced from GMOs but does not contain them. Labelling of GMOs is mandatory to give European consumers the right to choose whether or not they wish to buy foods containing GMOs.[15] New regulations for the labelling and traceability of genetically modified (GM) food came into force throughout the EC in 2004.[16] These regulations are intended to facilitate the commercialization of GM foods. Member states have the right to define penalties for infringements, but many have not yet determined such penalties or enforcement procedures. In addition, the regulations will be phased in gradually because of the differing processing times and life cycles of the products concerned. Greater harmonization may await a new regulation for food and feed control systems, unlikely to come into force until 2006 (Anon, 2004).

Even before these regulations were first proposed in 2001, other events created a seemingly insurmountable barrier to biotechnology innovation in the food and drink sector. Monsanto

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[15] The threshold of foreign DNA triggering mandatory labelling is 1%.

[16] See http://europa.eu.int/comm/dgs/health_consumer/library/press/press298_en.pdf for detailed information on these regulations.

introduced its GM “Roundup Ready” soyabean to the European market in 1996, at a time when there were no specific regulations in place for genetically modified foods. These soyabeans came from plants that had been modified to make them herbicide resistance. The GM soyabeans met with strong public opposition, although the strength of public opposition varied from country to country. The unclear regulatory environment for GM food was perceived as an institutional vacuum and it was filled by private initiatives. In response to public concern about GM, food retailers and food manufacturers quickly moved to establish voluntary standards and labels relevant to their markets. With almost no exceptions, they introduced *de facto* regulation by introducing "zero-tolerance" to GM ingredients. Zero tolerance standards led to the reformulation of processed foods to remove biotechnology products or their derivatives and to identify traceable supply chains to ensure the absence of such products. Thus, the voluntary GMO-free standards have quickly become the benchmark, making other standards and regulation mechanisms irrelevant. Ramón et al (2004) suggest that the “requirement established … for detailed environmental risk evaluation of GM foods, as well as for their labelling and traceability to the marketplace, should avoid the polemics regarding safety and labelling, which have been evident within the European Union.” Moreover, they believe that the opportunity for the Council of Ministers to use a qualified majority for the approval or rejection of a GMO should override the *de facto* moratorium currently exercized by some member states.

The reaction to GM soyabeans revealed the lack of demand in Europe for GM foods. This is perhaps the highest barrier to biotechnology innovation for the food and drink industry. Lack of demand results from public anxiety about foods derived from GMOs or based on the genetic modification of animals. The public is worried about the impact of GMOs on the environment and on human health, and on the possibility of animals suffering as a result of genetic modification (Straughan, 1995). Gaskell et al (2000) suggest that regulation and public opinion co-evolved in Europe and US. In the EU, increased regulatory oversight coincided with growing negative public opinion about agro-biotechnology and diminishing trust in public authorities and regulatory agencies. Public scepticism about regulation was reinforced by crises like BSE and foot and mouth disease. There was also growing distrust of methods used to produce foods in the agro-food and agricultural sectors - the use of pesticides, growth hormones or factory farming – and a growth in demand for organic foods.

Several studies have been conducted across Europe to gauge public perceptions to biotechnology. Over time, public opposition to food biotechnology has grown, especially between 1996 and 1999. The level of opposition to GM foods was lowest in The Netherlands, Finland and Spain. By 2002 opposition stabilized across Europe as a whole. The public thinks GM foods have no consumer benefits, and therefore are not prepared to accept any risks associated with them. By 2002, in a few countries there was evidence of slight growth in public acceptance of the GM foods, and tolerance of risk, so long as there were consumer benefits (Durant et al, 1998; Gaskell et al, 2000; Gaskell et al, 2003). Other recent work also suggests that the climate of public opinions toward GM foods may be softening. A Delphi survey found that experts

> "expect …a kind of 'habituation' of the consumer to this type of product in around ten years. In this context, food products which offer clear benefits to the consumer are best suited for taking the lead … . One example are [*sic*] probiotic foods[17] or other food products supporting health requirements." (Menrad et al, 1999)

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[17] Probiotic foods are also known as neutraceuticals or functional foods.

A consumer survey conducted in Belgium in 2000 confirmed that consumer acceptance of GM food is positively influenced toward those with health benefits. There were also positive attitudes toward food with environmental or price benefits (Verdurme et al, 2003).

The next section provides some information about the extent to which European companies are exploiting biotechnology. It reviews both the results of a European study, which examined biotechnology development in eight European countries, as well as more detailed, up-to-date information about the biotechnology activities of food firms in two small countries.

5 Current Biotechnology Activities in the Food and Drink Sector

This section, about the current biotechnology activities of the European food and drink sector shows that companies are very attentive to public attitudes in their exploitation of biotechnology. The EBIS project (Senker et al, 2001) provides information about the industrial exploitation of biotechnology in three sectors[18] and in eight countries: Austria, France, Germany, Greece, Ireland, The Netherlands, Spain and the UK. The information on the agro-food sector is drawn from an analysis of the database of firms active in biotechnology in the eight countries.[19] The EBIS project defined the term agro-food biotechnology as the application of biotechnology both to agriculture (seed and

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[18] The biopharmaceuticals, agro-food and research equipment and supplies sectors.

[19] Relevant companies in each country were identified from directories, media reports, government ministries and the Internet. Details about their activities relied on a variety of sources including use of a questionnaire, and material from a variety of secondary sources. The survey was carried out in 1999-2000.

agrochemical firms), and to food production (for control processes or diagnostics). The breakdown of firms by sub-sector is based on the firms’ main market.

Table 2: Breakdown of firms by sub-sector

No. of firms by sector	Austria	Germany	France	Greece	Ireland	The Netherlands	Spain	UK	Total
Agro-food biotech	3	20	59	12	6	34	22	6	162
Biopharmaceuticals	13	71	88	4	14	29	21	98	338
Research equipment and supplies[20]	3	54	22	0	3	33	6	103	224
Total	19	145	169	16	23	96	49	207	724

Table 2, the number of firms in each sector, shows that the agro-food sector is the smallest of the three sectors (162 firms). The low number of firms involved in agro-food biotechnology may be caused by unwillingness to identify themselves as players in the biotechnology sector because of negative consumer attitudes. Some may be involved in research but waiting to exploit it when public attitudes are more favourable.

The results may also be affected by different conceptions of what constitutes agro-food biotechnology. At its most limited, this would include only firms in the core of the sector. Firms that are suppliers of biotechnology products to the agro-food sector would be excluded because their core activity is in other sectors, such as pharmaceuticals, fine chemicals or services. A broader approach would include firms that provide services for the agro-food sector, like those involved in diagnostics or in the production of diagnostic kits.

[20] This sector provides the instrumentation, materials and services necessary for undertaking biotechnology research.

Our analysis also showed that the firms in the agro-food sector were older and larger than in the other two sectors and also included the highest proportion of subsidiaries. These subsidiaries may act principally as suppliers to their parent companies. Almost every firm is involved in R&D collaborations, mainly with domestic and European partners. The finding that collaborations with public sector partners predominate over those with other firms mirrors the findings of the analysis by Valentin and Jensen (2003) of lactic acid bacteria patents (see section 2 above).

An analysis of the factors affecting innovation in the sector found that public sector biotechnology research related to agriculture and agro-food received much lower funding than that in the biopharmaceuticals area. Moreover, most of relevant research was funded by public (national or the EC) sources. Germany, France and The Netherlands make the largest investment in public sector research and mainly focus on plant biotechnology. Spanish agro-food biotechnology research is growing in strength. The UK and Ireland also invest in plant biotechnology and plant science but these investments do not generate commercial activity.

Industrial activity is strongest in Germany, France and The Netherlands, partly due to the activities of large, domestic multinational companies and their subsidiaries. France, The Netherlands and Spain also have the most small biotechnology firms in the sector. In the latter two countries, this could be due to the strong agricultural traditions of these countries, together with muted public opposition to agro-food applications of biotechnology. The small number of agro-food biotechnology firms in the UK is difficult to explain. The UK has a strong science base in the area and there is a national emphasis on commercialising that science base. The campaigns of public interest groups, reinforced by media coverage and the response of concentrated food retailers appear to have created an environment where venture capital is loathe to invest in these firms. Alternatively those companies that are involved may not be prepared to admit that they are active in the area.

To sum up, the development of the agro-food biotechnology sector faces considerable barriers. The countries best placed to develop their competences are France and The Netherlands, based on their science base, their multinational companies and, in The Netherlands, muted public opposition to GMOs. Spain's fast-growing science base, and relative lack of public opposition to GMOs gives it the potential to develop national strength. The main brake on the development of food biotechnology, however, is the weakness of private investment in R&D, together with non-availability of venture capital to support the formation of small firms. In that respect, it is crucial for there to be greater awareness of the important role that public policy can play in supporting agro-food biotechnology research and use, especially development of the scientific knowledge base, evolution of technology transfer mechanisms and finally, policy to promote public acceptance of a reasonable use of biotechnology.

There is very little recent information about how food companies in Europe are now exploiting biotechnology. However, surveys of biotechnology firms in Finland and Ireland were undertaken during 2004. These countries are by no means representative of EC member states as a whole, but the information about how their food companies are exploiting biotechnology may provide clues to more general trends that may be emerging.

5.1 Finland:[21] A survey of biotechnology firms in Finland found that eighteen, out of approximately 110-120 identified, were involved in the food sector in some way. Of these, five are multinational companies or their subsidiaries: one is involved in ingredients and functional foods, another is in functional food only, one is in enzymes and food ingredients, one is in food ingredients only and one is in enzymes only. The thirteen remaining firms are all DBFs. Three are involved in diagnostics, five are in functional food, three provide R&D services to the food sector and two are involved in supplying food ingredients. One of these DBFs specializes in ingredients for functional food. It is interesting to note the medical interests of three of these companies. Pharmaceutical companies are the main customers of one of the firms supplying R&D services, and a second company's products are specialized foods for hospital patients, designed to lower infection. The third company, involved in functional food, has recently merged with a drug development company.

5.2 Ireland:[22] The agro-food sector forms a major part of the Irish economy but, until recently, there was little exploitation of biotechnology. Since 2000 the government has launched several initiatives to promote the diffusion of biotechnology to the food sector (Burke et al, 2001). An analysis of Irish biotechnology companies listed by BioResearch Ireland, a government agency that promotes biotechnology research and its commercialisation, identified nine companies involved in aspects of biotechnology relevant to the food sector. One Irish multinational, the fourth largest dairy company in Europe, began

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[21] Private communication from T. Luukkonen, The Research Institute of the Finnish Economy (ETLA), Helsinki, based on ETLA database of Finnish biotechnology firms.

[22] Based on Burke et al (2001) and a list of companies supplied by BioResearch Ireland to the first author in 2001, which has been updated via BioResearch Ireland’s website at http://www.biotechnologyireland.com/default.asp

work on a new Irish R&D facility in 2004. It will focus on developing ingredients for functional foods and plans to work closely with Irish academic researchers and biotechnology companies (Enterprise Ireland, 2003). Ireland is also home to a subsidiary of a US food ingredients MNC and its European biotechnology R&D centre. One former DBF, now part of a privately-owned group of firms, develops systems to treat industrial effluents, including those of food companies. Three DBFs are involved in diagnostics: one provides diagnostic kits and materials for the food and drink industry, another provides diagnostic kits and testing services and the third provides testing services only. The other three DBFs are all involved in producing ingredients for functional foods and all focus on probiotic products to ameliorate medical conditions. For instance, one provides an anti-microbial ingredient suitable for medical foods and nutrition.

6 Conclusions

This chapter has reviewed the opportunities and barriers to biotechnology innovation in the European food and drink sector. It has shown that science based innovations are not central to the sector and, at present, biotechnology applications are not part of the core innovation process for the food and drink sector. Application is held back by lack of economic incentives, regulatory uncertainty and consumer opposition to GM.

However, there are indications that biotechnology innovation in the food and drink sector will make slow progress in the next five to ten years, especially in diagnostics, process improvements or intermediate products (e.g. enzymes and other food ingredients) for the food and drink sector. However, these innovation will mainly come from companies in industrial sectors that act as suppliers to the food sector. Multinational companies will continue to build up their expertise in biotechnology so as to be able understand the advantages of new products and processes offered to them by suppliers and to be able to exploit the market when market conditions become more favourable. In due course, successful experiments with functional foods may give food and drink companies greater confidence to apply biotechnology to the development of other products with clear consumer benefits.

Public policy has a role to play in supporting the adoption of biotechnology by the European food and drink industry. Firstly, there is need for continued national and EC funding of public sector research related to food biotechnology, even though this knowledge is not currently being exploited by industry. Supporting public sector research will enable European scientists to have the expertise to operate in international networks and, in time, will provide the qualified scientists and engineers for companies that wish to exploit biotechnology. It will also provide governments with the expertise to assess the risks associated with worldwide developments and to participate in international negotiations – as well as capturing spillovers from external knowledge.

To ensure public confidence in food biotechnology, however, it is not sufficient to build up research capabilities, it is also necessary to invest in systematic bio-safety research and testing capabilities for novel foods and ingredients. This will provide a framework for communicating to the public about safe and beneficial applications of biotechnology.

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